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Lunar Studies

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Principal Investigator: Professor Thomas Gold

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1. INTRODUCTION

In the past half year, laboratory research has been fully concentrated on the elucidation of the processes which darken the lunar surface.

We have pursued our efforts toward the chemical analysis of the surface of rock powder grains before and after being subjected to simulated solar wind.

A sample preparation method has been developed that makes Auger analysis of insulating powder surfaces reliable and minimizes the "charge-up" problem. Modification on some of the electronic components of the Auger electron spectrometer further increased the signal-to-noise ratio. The quality and reproducibility of our Auger electron spectra thus have much improved and we have already obtained, for example, a series of very informative spectra of lunar dust.

Much effort has been spent on the reconstruction of the solar wind simulator (high vacuum, proton (or α-particle) bombardment chamber) which had been extensively used in our laboratory by Hapke. This system was originally built some ten years ago and needed a considerable amount of repair and modification for our present experiments.

We also conducted a study of the variation of the optical properties of Apollo 15 deep drill core samples as a function of depth below the surface. We compared the albedo variation with depth to the variation of cosmic ray track density with depth in order to see if any correlation exists. Such correlation would demonstrate the dependence of albedo on the length of exposure of the dust grains to solar wind.

Theoretical work was continued on surface transportation effects on the Moon. A statistical Monte Carlo calculation has been carried out to reconstruct the effects of random mixing that would be needed to achieve the uniformity of surface exposure of dust grains. These calculations made it clear that processes other than random mixing by micrometeorites must be involved.

II. EXPERIMENTAL RESEARCH

A) Auger Analysis of Lunar Samples and Proton Bombarded Terrestrial Rock Samples.

In order to observe characteristic Auger peaks of such elements as iron and magnesium, common both in terrestrial and lunar rock powders, we have to bombard the surface of these powders with electrons of 2000-3000 V energy. At these primary electron energies the secondary electron emission coefficient is below unity for most powders and their surfaces thus charge up negatively. This charge, however, is unstable and the Auger spectrum obtained under such a condition is unreliable. We have discovered, however, that the cross-over voltage of the secondary electron emission coefficient and thus the "charge up" effect is greatly dependent on the geometry and microstructure of the powder surface. Flat and smooth sample surfaces seem to have higher secondary electron emission coefficients so that the observed negative charging is less. With such sample surfaces we were able to obtain Auger spectra indicating only some 20-40 V negative charge on the sample.

This charge is stable and the spectra are reproducible. Figure 1 shows the spectrum of an Apollo 11 dust sample. Elements such as iron and titanium, which are only present in a few atomic percent in the sample (in bulk concentration) are clearly distinguishable in this Auger spectrum.

The quality of our recent Auger spectra was also enhanced by modification of some of the electronic components of the spectrometer. Figure 2 shows a block diagram of the signal acquisition electronics. A specially constructed low noise FET preamp and a neutralization network are the salient additions to these electronics. Figure 3 shows in detail the modulation and neutralization units.

In addition to the above modifications a temperature control has been constructed for the electron gun to keep the filament temperature constant, in turn keeping the filament emission constant. This circuitry appears to be a significant improvement over the previous unregulated D.C. voltage source.

The analytical tool being satisfactory for the project, our attention has been turned to the improvement of the solar wind simulator. This apparatus gave very good performance for a number of years in the past but it needed much repair, maintenance work and minor modifications in order to obtain sufficiently high vacuum for successful proton bombardment experiments. The pumping system, the water cooling system, the ion source, the cold trap cooling system, all had to be taken apart, cleaned and some of their components changed or redesigned. Repair work had to be done on the oven, the oven control and other control electronics.

At this point it is possible to obtain sufficiently high vacuum (2×10^{-8} torr) in the apparatus but there is some problem with back streaming oil from the diffusion pump and the resulting contamination of the ion bombardment chamber. The first Auger spectra taken of irradiated samples will indicate the level of the contamination. Changing the cooling agent in the trap above the diffusion pump from Freon cooled methanol to liquid N_2 might very well solve the problem.

We expect to start the irradiation experiments on terrestrial and lunar samples and the subsequent Auger analysis of these samples, soon.

B) Optical Properties of the Apollo 15 Deep Core Samples

The albedo of 17 powder samples from the Apollo 15 deep core tube was determined. The position of these samples ranged from 15 cm to 108 cm depth from the top of the core.

Figure 4 shows the albedo, normalized by comparison with MgO, as a function of depth in the core tube, at $\lambda = 5500$ Å and at a phase angle of 7°. Due to the minute quantities of core samples available, the reflectivity measurements were made with very small (4mm in diameter) sample surfaces. In order to increase accuracy, every measurement was repeated with three different sample orientations and the data points represent the arithmetic average of these measurements. The upper and lower limits are also shown. The different curves connect data points obtained with different sample preparation methods (as indicated in the figure). The albedo at 0 cm depth is that of a typical Apollo 15 surface sample, the top of the core sample not being available.

It is evident from Figure 4 that the variation of albedo with depth is significant. If we take the results obtained with the loosely compacted sample (perhaps the closest to the actual lunar situation) we find the albedo varies between 9.3% (at 15 cm depth) and 15.2% (at 63 cm depth) and that this variation is a seemingly random function of depth. Bowell et al. (1) examined some 17 surface fines from the Apollo 11 to 15 sites and the Luna 16 and 20 sites and found that the albedo of these samples (at $\lambda = 5850$ Å and at a phase angle of 5°) varied between $\sim$ 7.5% and 16.5%. Thus, just probing to 1 meter depth below the surface one encounters almost as significant a variation in the optical properties of the samples as the regional variations over the entire Moon.

It is also remarkable how sharply the albedo changes with a small change in depth. At 63 cm depth, for example, the albedo is 15%, whereas at 63.5 cm it is 12.7%. This again, as we pointed out earlier (2) indicates the existence of a surface transportation mechanism which is capable of depositing a very thin layer of soil without mixing it with the underlying layer.

In Figure 5, we plotted the minimum cosmic ray track density counts (according to Fleischer and Hart (3)) in samples of one core tube section, along with our albedo results. These curves indicate a rather striking positive correlation between track density and albedo, suggesting that different layers had suffered a different history of surface exposure related to the darkening process. Comparisons of different regional samples had also suggested a relationship (Price et al. (4)) but of the opposite sign. This is not necessarily in conflict, since many situations can be envisioned where such a correlation, if it exists, can be of either sign. It is clear that a further study of this relationship would be most interesting both with surface and core samples.

References

1. Bowell, E., Dollfus, A., Zellner, B., and Geake, J.E. (1973), Proc. 4th Lunar Science Conf., 3, 3167-3174.

2. Gold, T., Bilson, E., and Yerbury, M. (1973), Proc. 4th Lunar Science Conf., 3, 3093-3100.

3. Fleischer, R.L. and Hart, H.R., Jr. (1973), Earth and Planetary Science Letters, 18, 420-426.

4. Price, B.P., Rajan, R.S., Hutcheon, I.D., Macdougall, D., and Shirk, E.K. (1973) in "Lunar Science IV," 600-602, The Lunar Science Institute, Houston.

III. THEORETICAL RESEARCH

A) Mixing and Layering of the Lunar Soil

The information on surface exposure provided by the cosmic ray tracks and the solar wind implantation requires a large proportion of the grains to have spent some time on or close to the surface. The presence of distinct layers in the soil precludes an explanation in which meteoritic mixing has been very thorough.

We have carried out a statistical Monte Carlo calculation to reconstruct the effects of random mixing that would be needed to achieve the observed uniformity of surface exposure. From this it is clear that effects other than random mixing must be involved. It appears that a progressive build-up of the surface must be postulated that is fast enough to beat the rate of meteorite mixing in most localities, and that in this process each grain had a high probability of being on the surface. This indicates that most of the ground sampled so far is in areas that are accumulating (and not denuding) by a surface transportation process.

PUBLICATIONS

Conjectures about the Evolution of the Moon. T. Gold, The Moon 7, 293-306 (1973).

The Simulation of Lunar Micrometeorite Impacts by Laser Pulses. E. Bilson, T. Gold and G. Gull, The Moon 6, 405 (1973).

Electrostatic Effects on the Lunar Surface. T. Gold and G. J. Williams, in "Lunar Science V", in press.

Mixing and Layering of the Lunar Soil. T. Gold and G. J. Williams, in "Lunar Science V", in press.

Optical Properties of the Apollo 15 Deep Core Samples. T. Gold, E. Bilson and R. L. Baron, in "Lunar Science V", in press.

FIGURE CAPTIONS

Figure 1. Auger electron spectrum of an Apollo 11 lunar dust sample, showing Auger peaks up to 850 V. (The primary electron energy is 1650 V.)

Figure 2. Block diagram of the analyzer unit of our Auger spectrometer

Figure 3. Circuit drawing of the Auger modulator and neutralizer

Figure 4. Variation of albedo of 7° phase angle as a function of depth in the Apollo 15 deep core samples

Figure 5. Comparison of the variation of albedo and that of the cosmic ray track density counts as a function of depth in the Apollo 15 deep core samples

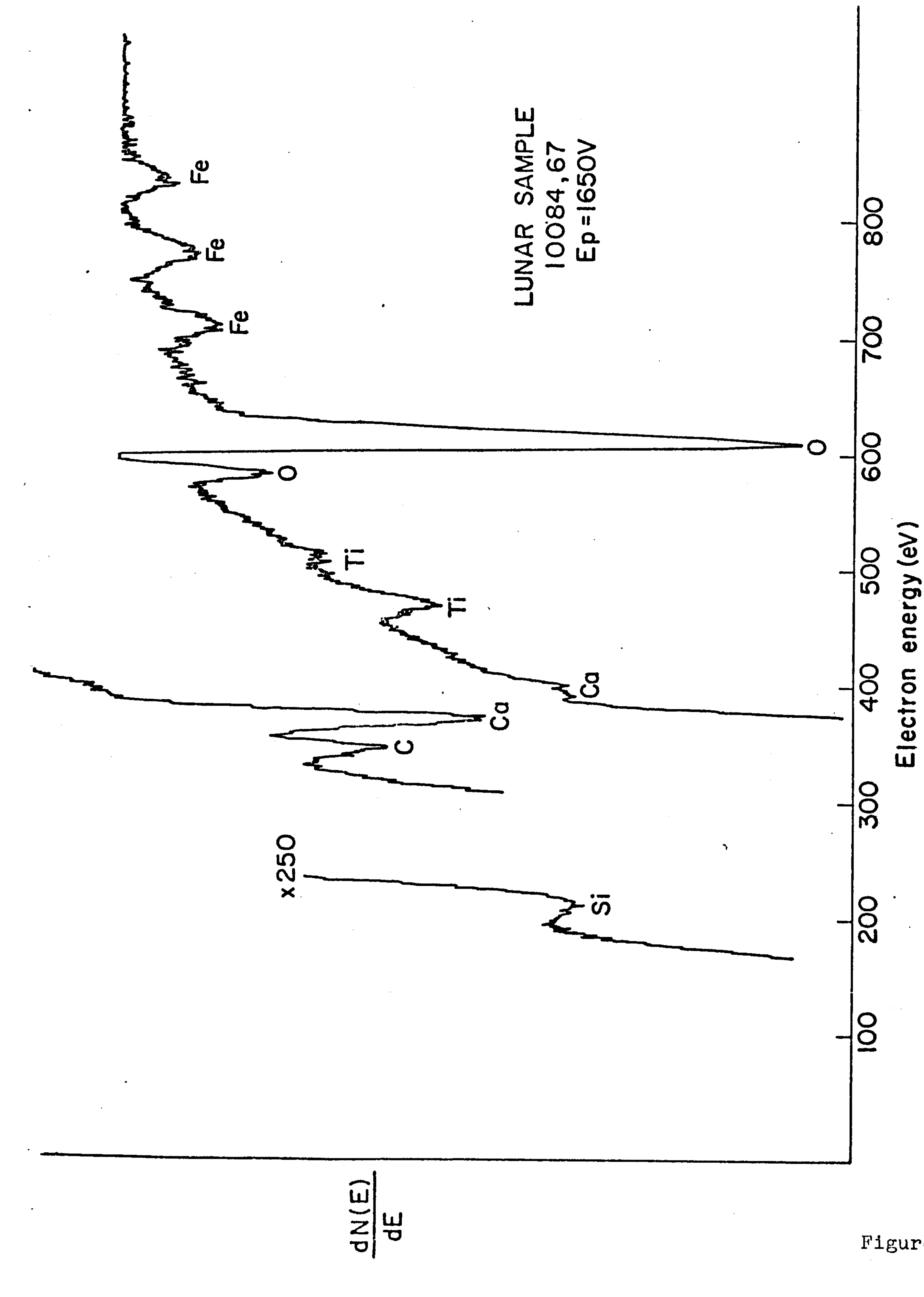
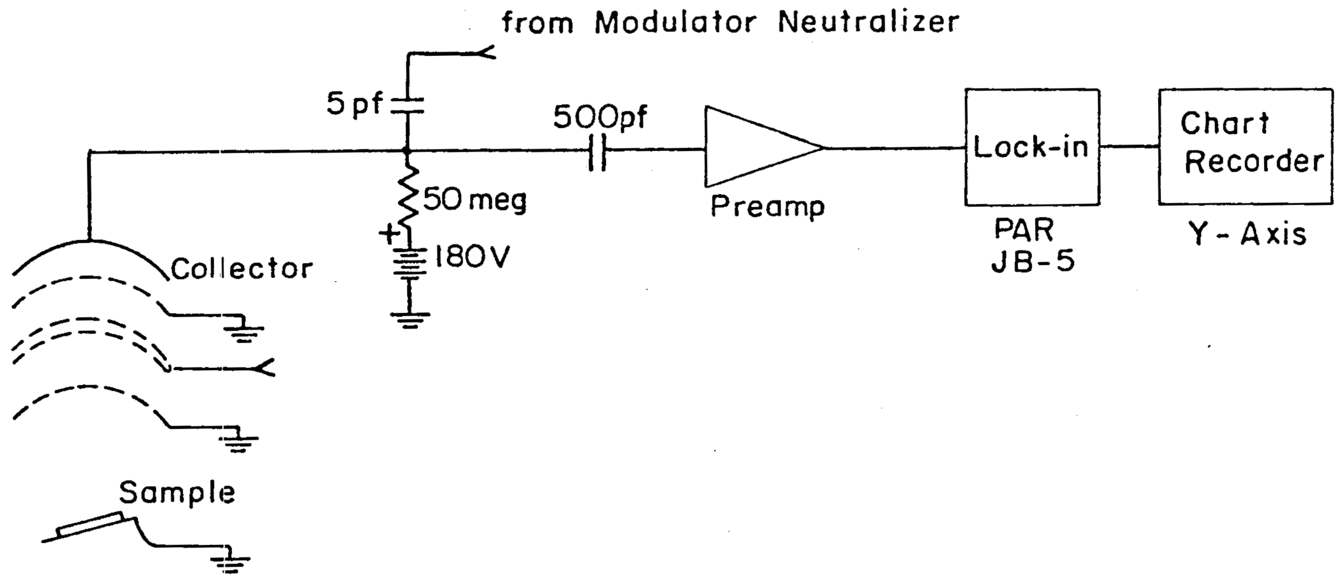

LUNAR SAMPLE
10084,67
Ep=1650V
x250
Si
C
Ca
Ca
Ti
Ti
O
O
Fe
Fe
Fe
100
200
300
400
500
600
700
800
Electron energy (eV)
dN(E)/dE

Figure 1.



AUGER SIGNAL ACQUISITION

Figure 2.

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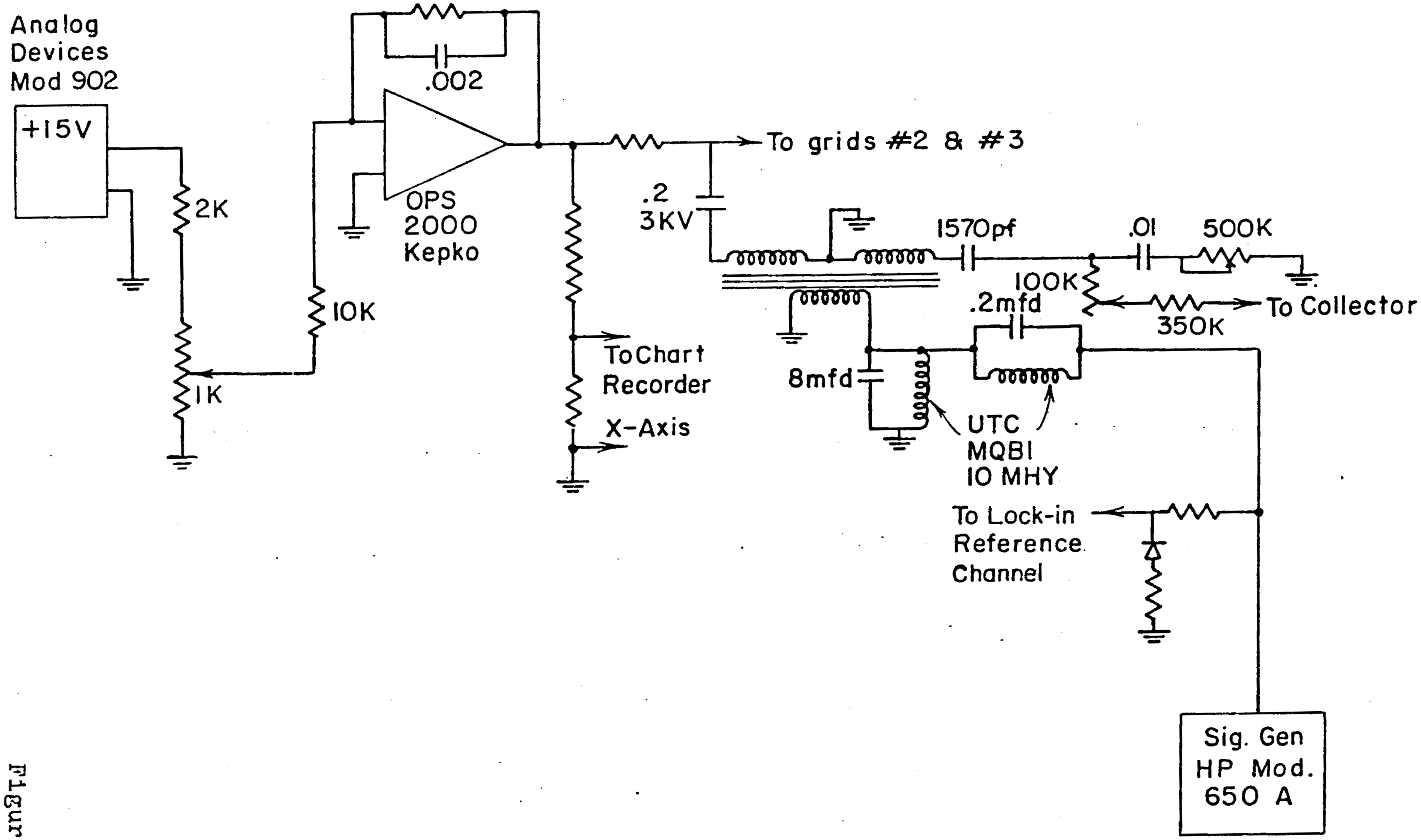

AUGER MODULATOR AND NEUTRALIZER

Nov. 1973

Figure 3.

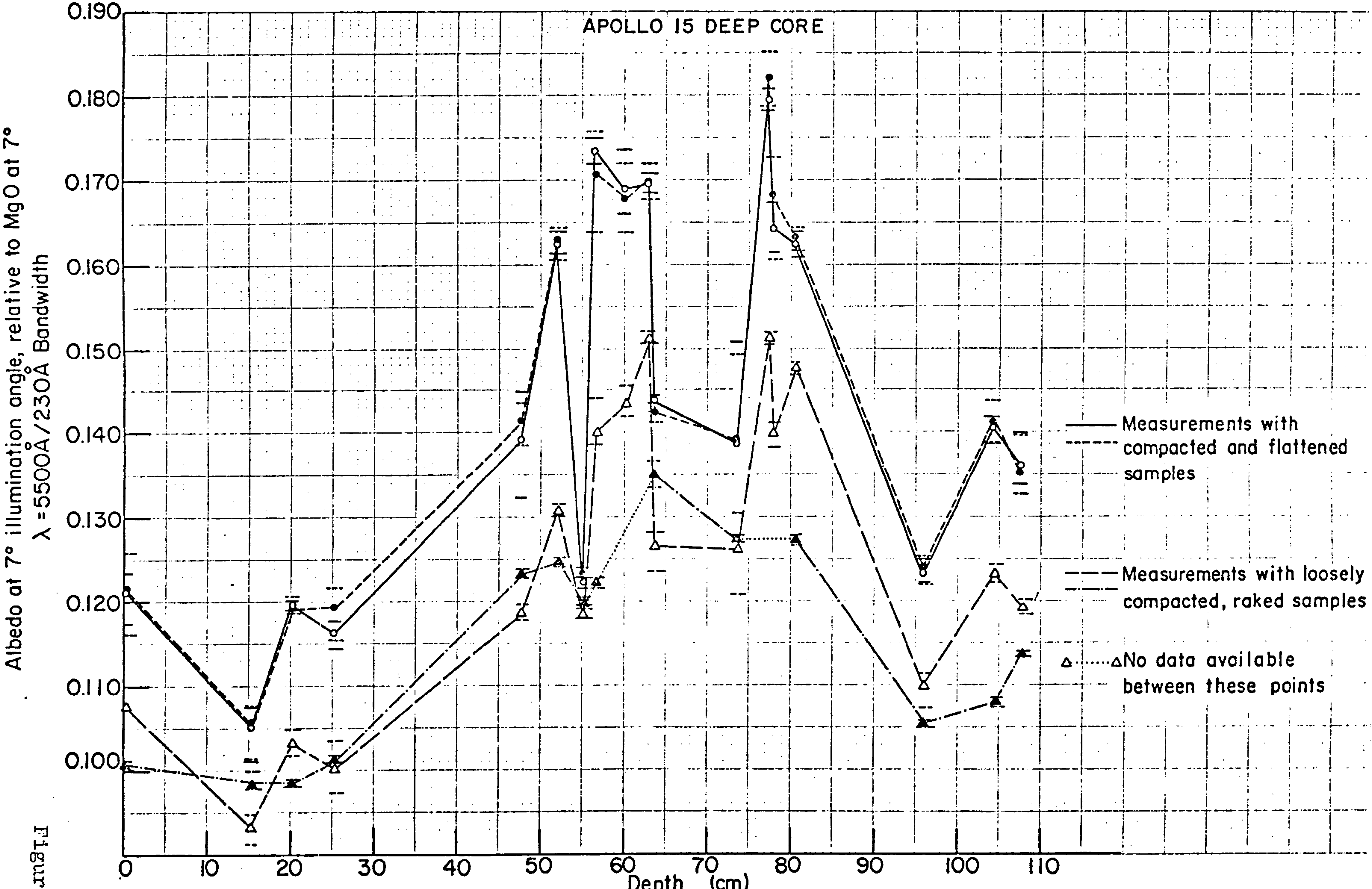
APOLLO 15 DEEP CORE
Albedo at 7° illumination angle, relative to MgO at 7°
λ = 5500Å/230Å Bandwidth
0.190
0.180
0.170
0.160
0.150
0.140
0.130
0.120
0.110
0.100
0
10
20
30
40
50
60
70
80
90
100
110
Depth (cm)
Measurements with compacted and flattened samples
Measurements with loosely compacted, raked samples
Δ……ΔNo data available between these points

Figure 4

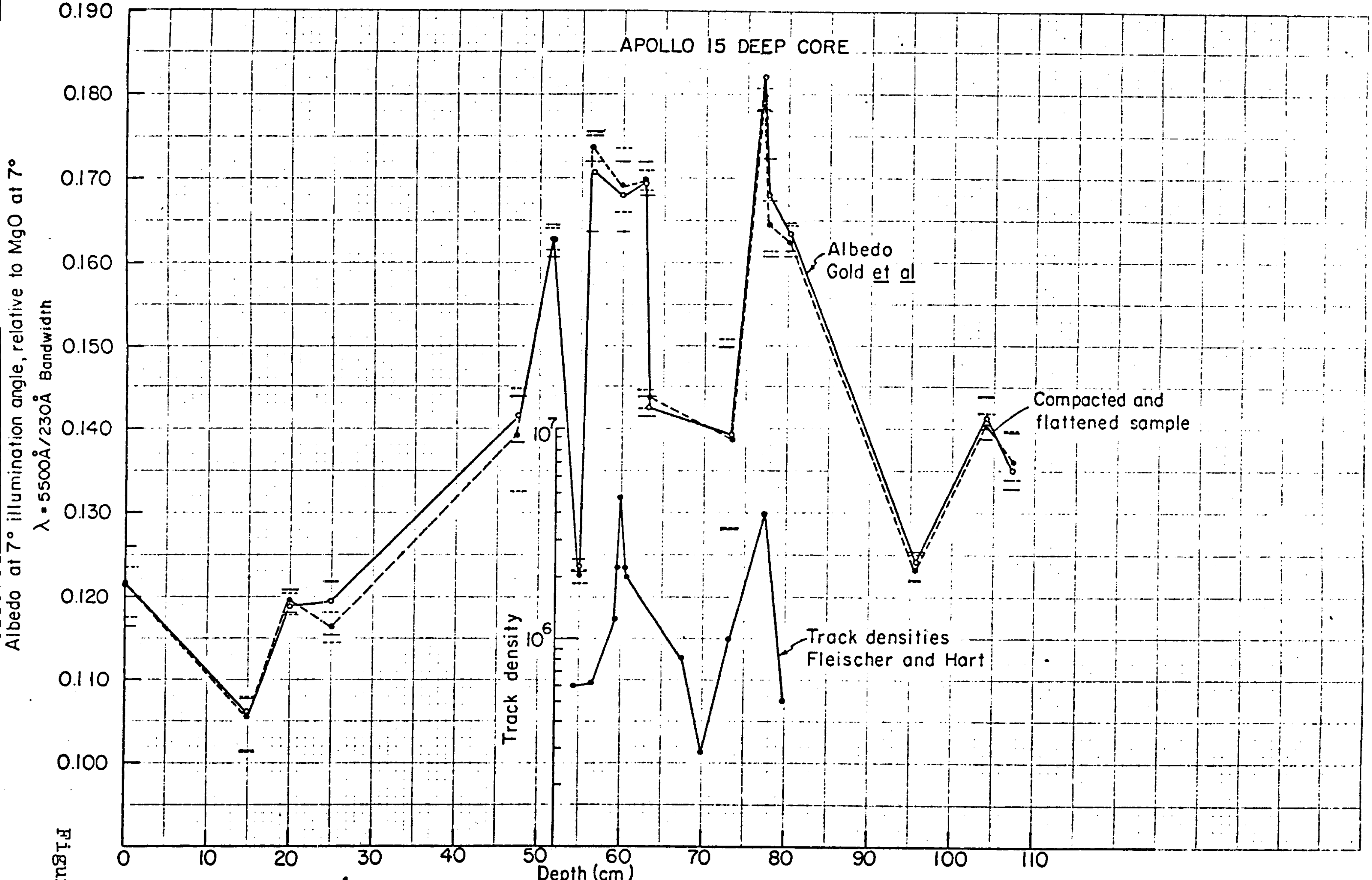
APOLLO 15 DEEP CORE
Albedo at 7° illumination angle, relative to MgO at 7°
λ = 5500Å/230Å Bandwidth
0.190
0.180
0.170
0.160
0.150
0.140
0.130
0.120
0.110
0.100
Albedo
Gold et al
Compacted and
flattened sample
Track densities
Fleischer and Hart
Track density
10^7
10^6
0
10
20
30
40
50
60
70
80
90
100
110
Depth (cm)

Figure 5.